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ABSTRACT

To stimulate research proposals, the report stresses the need for a comprehensive research and development program regarding sensory aids for the visually handicapped and describes 17 representative projects viewed as warranting immediate attention. The 17 projects are categorized in two different ways. In a brief summary section, projects are classified according to whether they relate primarily to organization and planning or to R and D needs. Provided in the next section is a more detailed description of short-term projects that may be expected to yield successful early results (including new reading and mobility aids for the blind and studies of visual capabilities among the partially sighted) as well as long-term projects (involving broader research in such areas as vocational opportunities, public information programs, sensory aids centers, technological applications, and research on the reading process among sighted individuals). Also listed are 19 source documents said to define problems, to describe the current state-of-the-art, or to indicate organizations and people currently active in the field of sensory aids for the visually impaired. (LH)

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SELECTED RESEARCH, DEVELOPMENT AND ORGANIZATIONAL NEEDS TO AID THE VISUALLY IMPAIRED

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Subcommittee on Sensory Aids
COMMITTEE ON THE INTERPLAY OF ENGINEERING WITH BIOLOGY AND MEDICINE

NATIONAL ACADEMY OF ENGINEERING

Washington, D. C.

May, 1973

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The National Academy of Engineering, aware of its responsibilities to the government, the engineering community, and the nation as a whole, is pledged:

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FOREWORD

In June, 1967, the National Academy of Engineering established the Committee on the Interplay of Engineering with Biology and Medicine under a contract with the National Institutes of Health. The broad purpose of the Committee is to delineate the ways in which our national engineering capability and modern engineering theory and practice can contribute to the solutions of problems in biology and medicine.

One technique employed by the Committee addresses pertinent topical areas through Subcommittee action. The Subcommittee on Sensory Aids was formed in 1969 to stimulate, innovate, correlate and recommend research, development, evaluation and deployment efforts on sensory aids for the hearing and visually impaired.

In regular meetings, conferences, and workshops, in the pursuit of their own research and in their familiarity with other investigators and projects in the United States and abroad, the membership of the Subcommittee has become aware of the current status of sensory aid needs, accomplishments and opportunities. The primary purpose of this report is to identify by means of an annotated list those areas which, in the view of the Subcommittee, warrant further research and development. Topics are described briefly and are categorized as either short- or long-term efforts. The report is not intended to imply that all of these topical areas are currently not receiving attention. Work in several areas is underway at various places in this country and elsewhere.

This report does not deal per se with the evaluation of sensory aids. That important topic has been the subject of a specific Subcommittee workshop on the Evaluation of Mobility Aids for the Blind. A select international group of experts assessed plans and programs for the evaluation of several specific mobility aids. Other aspects of sensory aids evaluation were also covered in a similarly structured

Conference on Sensory Training Aids for the Hearing Impaired. Proceedings of both these workshops are available from the National Academy of Engineering. *

The Subcommittee also recognizes the urgent need for focusing and structuring the national research, development, evaluation and deployment effort in the sensory aids area. A report "Sensory Aids for the Handicapped: A Plan for Effective Action" delineates alternative mechanisms to link research and social needs to stimulate the development and delivery of appropriate sensory aids to the blind and deaf.

Although we hope that the contents of this report will not escape the attention of those already involved in sensory aids development and application, it is especially directed to the dynamic teacher and clinician whose experiences and ideas can contribute to the greater efficacy and adoption of sensory aids to the visually impaired. Equally important, the report is intended to mirror needs and opportunities for those benefactors--both Government and private--who may be seeking to identify worthwhile projects for application of their resources and who are responsible for organizing the nation's capacity to implement effective programs.

Finally, one of our prime goals is to stimulate new concepts and encourage creative minds to enter this exciting arena. We offer to scientists and engineers seeking new applications for their talents a field that is both intellectually challenging and humanly rewarding. Tangible benefits are realized by society when the handicapped person is prepared for

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* Proceedings of the Conference on the Evaluation of Mobility Aids for the Blind. P.W. Nye, (Ed.). National Academy of Engineering, Washington, D.C., 1971.

Proceedings of the Conference on Sensory Training Aids for the Hearing Impaired. Harry Levitt and P.W. Nye (Ed.). National Academy of Engineering, Washington, D.C., 1971.

a self-supporting adulthood; but solely on a humanitarian basis, even partial amelioration of vision loss is warranted when a blind person is thereby enabled to enjoy a more self-fulfilling life.

Robert W. Mann, Chairman
Subcommittee on Sensory Aids

ACKNOWLEDGMENTS

The Subcommittee on Sensory Aids would like to acknowledge the significant contributions to this report made by two of its former active members (now consultants to the Subcommittee): Dr. James C. Bliss, Stanford Research Institute, and Dr. Carson Y. Nolan, American Printing House for the Blind.

In addition, a debt of gratitude is due Subcommittee member P. W. Nye who assembled and edited the text, to Charles W. Garrett, Executive Secretary of the Subcommittee who offered valuable comment and supervised the final editing and publishing of the document, and to Marianna Shepard who diligently and capably typed the manuscript and prepared the camera-ready copy of the text.

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INTRODUCTION

A coordinated program of research and development in the field of sensory aids is necessary if the potential of currently available knowledge for solving the needs of the blind is to be realized. In this document itemized lists of research and development needs are given to outline the components of such a program and to stimulate the development of individual research proposals. The areas selected are, in the collective judgment of the National Academy of Engineering's Subcommittee on Sensory Aids, * those that would contribute most to such a coordinated program.

In structuring a comprehensive program of sensory aids development, two competing action philosophies must be balanced. On the one hand, a "home run" is needed. A clear and striking success will generate interest, confidence, and funds. On the other hand, only a concerted, broad, integrated program of research, development, evaluation, and deployment can achieve long-term successes in the full range of sensory aids devices and systems for the blind.

The difficulty in striking a balance between these approaches arises in no small part from the need to assign priorities. The relative importance of the number of factors on which priority must be based, among them the urgency of the need and the current level of development, will fluctuate as the program develops. Hence, priority assignments cannot be regarded as permanent; it will be necessary to keep the ordering of the project lists under careful scrutiny.

During the early stages of the program, broad questions must be addressed: What is needed? By whom? What gaps in our knowledge of the blind must be filled? What

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* The Subcommittee membership is listed on page ii.

are the fundamental perceptual, physiological and technical areas that require support? The few demographic studies that exist need considerable extension to answer these questions.

Noble generalizations, however, must not be permitted to obscure the more immediate needs of the blind to earn a living, read, walk, and interact effectively with non-handicapped people. The goal of our Subcommittee is to speed the development of those devices and systems that are of direct, realistic and extensive utility to the blind.

The Subcommittee has listed seventeen specific projects which, in its view, warrant immediate attention. These descriptions, beginning on page six, are not intended to be exhaustive; rather, they are meant to be suggestive in order to stimulate further interest and exploration. They are divided into two categories--short-term projects which can be attacked immediately with the expectation of early results (i.e., creating the "home runs" referred to above) and those projects which should be initiated now with long-term objectives.

The summary, on the other hand, divides the listed projects in an alternative classification; those of an organizational nature and those involving sensory aids research and development. In neither the Summary nor the Description sections is any rank ordering of importance of the listed projects intended.

In lieu of text references, a short list of source documents is provided. In the judgment of the Subcommittee, these source documents represent the best available statements on the state-of-the-art and will lead the reader to the bulk of the literature on the various topics.

The Subcommittee invites comment and queries, addressed to:

Subcommittee on Sensory Aids, CIEBM
National Academy of Engineering
2101 Constitution Avenue, N.W.
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SUMMARY

Organization and Planning Needs

1. Demographic Surveys of Reading Aid Needs. Collection of data through demographic surveys of the visually impaired population to help establish the kinds and types of reading aids needed.

2. Demographic Surveys of Vocational Opportunities. Collection of data through demographic surveys of the visually impaired population to determine the vocational opportunities open to the visually handicapped, and the devices and services available to aid in their employment.

3. Public Information Programs. Stimulation of public awareness of the need for aids for the visually handicapped and of the potential of research for providing effective aids so as to develop a favorable climate for legislation and the expenditure of public funds to support research and services for the blind.

4. Multidisciplinary Exchange of Information. Organization of a series of conferences of acknowledged authorities in the fields of reading, vocational training, and mobility for the blind in order to assist the planning of research on sensory aids, the expansion of vocational opportunities, and the development of experimental techniques useful in evaluating sensory aids.

5. Sensory Aids Centers. Establishment of two or more national centers for sensory aids to implement programs in research, development, evaluation, and deployment, as first proposed in the National Academy of Sciences report "Sensory Aids for the Blind" and as developed in the National

Academy of Engineering action program report entitled "Sensory Aids for the Handicapped--A Plan for Effective Action."

Research and Development Needs

1. Automated Reading Services. Development of a time-shared computer system for generating voice tape recordings and braille translations of printed books and/or compositor tapes, including braille production from mathematical and musical notation as well as from conventional alphanumerics.

2. Computer-Aided Studies of Mobility. Development of a time-shared computer system for real-time interaction to permit realistic simulation and evaluation of mobility problems and of proposed devices and systems to aid mobility.

3. Research on Pattern Processing. Research on pattern-processing techniques for optical-to-tactile image conversion using both static and dynamic display, especially with control of the processing by the user.

4. Research on Sighted Reading. Fundamental research on the normal visual reading processes and on both normal and handicapped tactile reading in order to guide device and system design for optimum surrogate channel stimulation.

5. Pilot Studies of Automated Reading Services. Pilot studies of a time-shared computer system for reading documents, including examination of system logistics, cost-effectiveness, and user acceptance.

6. Automated Reading Services via Telephone. Development of a direct-access, time-shared computer system for reading documents scanned at

remote terminals (user's home, etc.) with output fed back to the user via telephone lines as synthesized speech, tactile alphanumerics, or braille.

7. New Reading and Mobility Aids. Development, evaluation and deployment of small, personally owned reading and mobility aids using new technologies.

8. Development of Tactile Stimulators. Engineering development of tactile stimulators and displays, both mechanical and electrical.

9. Research on Automated Braille Production. Research on ways to speed up and automate the production of braille.

10. Devices to Aid in Reading Visual Displays. Development of simple devices for reading visual displays to aid blind workers operating industrial tools, students using laboratory equipment (e.g., in physics and chemistry), etc.

11. Definition of Visual Capabilities among the Partially Sighted. Research on the varied visual capabilities of the partially sighted (severely visually handicapped) to more clearly identify their sensory aid needs.

12. Aids for the Partially Sighted. Development of aids (e.g., large-type newspapers, closed-circuit TV systems, optical enlargers) by which the partially sighted can gain immediate access to any printed matter.

DESCRIPTIONS OF SELECTED NEEDS

Short Term

1. Demographic Survey of Reading Aid Needs

The need for aids to enable the blind to gain access to information customarily available only in inkprint form has long been recognized. Braille, large type, recordings and sighted readers are the traditional techniques, all of which require intervention by others. Other methods have been sporadically explored, but such explorations have taken place in the absence of any information on the reading needs of the general blind public. Consequently, a demographic study is required to define and categorize reading needs and to establish priorities for research on devices and systems to meet these needs.

Important variables to be considered include the following:

a) Type of reader--student, housewife, businessman, etc.

b) Reading task--textbook, correspondence, can labels, money, etc.

c) Biographical data--degree of handicap, education, etc.

d) Type of material--type style, type size, variability, manner displayed, etc.

e) Preferred output--tactile, auditory, magnified visual image

2. Multidisciplinary Exchange of Information

The literature covering research on enlarging the reading and mobility opportunities open to the blind is small and relatively unknown. Moreover, the investigators involved in such research are often unaware of similar work being carried out by others. As a consequence, their work contains much duplication of effort, including the repetition of unfruitful research. The conference mechanism would be one effective method of developing and coordinating a research community to identify and promulgate worthwhile research in the sensory aids field.

3. Automated Reading Services

A computer system should be developed to generate automatically and at high speed (i.e., at a speed faster than real-time delivery) an intelligible spoken-word output from input received from a print recognition machine or teletypesetter tape. The output would be recorded on magnetic tape in Talking Book form for subsequent replay at normal speed. An alternative output could be provided in braille form, using either a specially constructed high-speed braille or a modified line printer.

The facility housing such a system would be expected to operate in close relationship with a large library and provide a fast service to blind persons in response to requests received by mail or telephone. The intent of the service would be to supplement the services of existing agencies, particularly in the area where existing services are weakest; namely, in speed of operation. The emphasis on high-speed, large-volume operation would necessitate the development of efficient automatic document-handling equipment and recognition algorithms capable of trouble-free service with a wide variety of document formats, sizes and type styles. The system as outlined here would probably require a dedicated computer system. A somewhat more flexible approach could be developed by utilizing a time-shared system as described below.

4. Pilot Studies of the Usefulness to the Blind of Automated Reading Services

Communications technology is developing rapidly, and large, centralized, time-shared optical character recognition facilities will eventually be widely employed by business organizations. These document readers also could provide services to the blind or dyslexic if used in conjunction with systems providing automatic speech synthesis, braille translation, or other forms of sensory display. To ensure that application of these systems to the sensorially deprived is not delayed, work should begin soon on an examination of the logistics, the cost-effectiveness and the likely user acceptance of such systems.

5. New Reading and Mobility Aids

Radar, sonar, and lasers afford an important potential means of assisting the blind to navigate safely and efficiently using portable systems, yet this potential remains largely untapped. Similarly, monolithic fabrication methods in the electronic component field, which permit the production of multi-element image sensors, open the way for the development of a variety of reading aids and mobility devices.

6. Tactile Stimulators

The cutaneous sense provides an input channel that is well attuned to spatial relationships. The skin surface will therefore accept information mapped in a two-dimensional space with a minimum of recoding. Many opportunities exist for the design of special stimulators and displays which can provide input at compatible locations on the body surface.

7. Research on Automated Braille Production

Braille-embossing hardware and machine-transferable computer programs for translating literary English into contracted grade II braille have recently become available. Workers for the blind, however, are generally unaware of these developments, and they lack experience on how to apply the

techniques to their particular service roles. Engineering faculty and students, in collaboration with agencies for the blind, can greatly facilitate training in the use of these techniques.

A fundamental barrier to the increased production of braille from ordinary inkprint is the mode of input. While optical character recognition offers one alternative, the type compositor's tapes currently used for the type-setting of inkprint books have been shown (on a very limited scale) to be another, more immediate source of input. Demonstration projects employing tapes from a wide range of media should be undertaken, in conjunction with braille translation computer programs, to develop and evaluate the efficacy of this approach. Surveys should be undertaken to establish the availability of type-setter tapes from publishers. The extent to which such tapes correspond to the final inkprint will determine the extent of editorial correction needed. The legal and financial aspects of the acquisition of type compositor's tapes for subsequent use in the production of braille or audio output for blind readers must also be determined. Consideration might be given to the establishment of a small-scale tape library as a source of transcription material. Such a library effort could point up practical problems and the potential of large-scale retrieval and storage programs.

8. Devices to Aid in Reading Visual Displays

Rehabilitation agencies serving the blind and visually handicapped have little or no access to technical aids which might enhance the employability of their clients. Few agencies have engineers employed to adapt industrial tools and instruments for the blind. It is the experience of many agencies concerned with the vocational rehabilitation of the blind that the provision of aids for unskilled and semi-skilled blind workers is often as difficult as producing aids for the most sophisticated, professionally trained blind. Often the investment in time and resources to provide tools for clients with a potential annual income of $6,000 to $7,000 is greater than the effort required for clients with an employment potential of $20,000.

One of the basic deficiencies of the blind in industrial jobs is their inability to receive feedback from instruments and written records. Feedback enables the operator of any machine to modify machine states and to monitor his responses to machine states. For example, a blind person on a quality control job must read instrument dials for which he usually needs special readout tools. He must also record and verify data for which he must read handwriting, typewriting, or graphs. Precise, quick-acting, blind display instruments with known input functions are needed to enable the blind to perform these industrial jobs.

Tactile displays have been developed by several individual researchers, but none is available to rehabilitation agencies. Instruments are available with combined audible and tactile readouts for measurements which can be transduced to voltages, but these are imprecise and slow-reading relative to industrial sensors for the sighted.

The engineer entering an industrial plant to modify tools and instruments for use by the blind must build instruments to sense machine states in blind-readable forms. On crude jobs, both sensor and display devices are often simple and easily built. As precision and sophistication increase, blind-readable displays become more difficult to build.

Transducing instruments for machine-state sensing are available for numerous industrial tools, and sensing instruments with known outputs are commercially available for all levels of precision. Because of the inherent variety in real situations, these instruments will always have to be tailored and interfaced to existing industrial equipment. Blind-readable displays for these sensors need not be custom made; they could be standard devices with known human-factor characteristics. It follows, of course, that input functions for blind-readable displays must be made compatible with the output functions of the most common transducing instruments.

Blind students in the sciences and in engineering need data displays which can be fitted with suitable transducers for making scientific measurements. While there is

nothing to indicate that the blind student's display should be different from the industrial worker's, the student should be equipped with a variety of transducers suitable for most educational scientific measurements.

9. Definition of Visual Capabilities among the Partially Sighted

Of those identified as being legally blind, only an estimated 10 percent are totally light deficient. The vision of the others ranges from only light perception to 20/200 vision and field restrictions. In order to devise specific aids and prosthetic systems, it is necessary to know what these partially sighted people can see and what kinds of aids they need for specific tasks. Clearcut answers are not given by the usual resolution chart or text-reading tests. This is particularly true for mobility problems where, for example, measurement and classification of levels of mobility disability in relation to conventional acuity measures are needed. Is 20/200 vision sufficient for crossing a street? Is 20/150 vision marginal for detecting curbs? And so forth. There are two ways to develop pragmatic answers to such questions. One, of course, is to test blind populations in controlled experiments. The other, which would establish upper limits of performance, is to test normally sighted persons whose vision is artificially degraded to precise levels by electronic or optical means.

The knowledge derived from such studies can be used not only to develop particular kinds of aids which span the range of needs but also to supply the theoretical limits of resolution required for particular tasks using surrogate sensory channels such as, for example, the sense of touch.

10. Aids for the Partially Sighted

Some 80 percent of the administratively or legally defined "blind" population has some residual vision. The need for adequate instrumentation to mobilize their remaining visual capacity is paramount, particularly in view of the current dearth of progress in this area. Suitable instrumentation, if widely available and used, could have an

economic impact in excess of the modest investment required. Of this relatively large total population of the partially sighted, however, the majority are elderly and there are great individual differences in the nature of their visual defects, a fact which must be kept in mind if the visual supplements developed are to have wide applicability.

The National Accreditation Council for Agencies Serving the Blind and Visually Handicapped has published suggested standards for large-print text that are endorsed by the American Foundation for the Blind, and a few optical enlargers are available which permit magnifications of up to ten times with fair contrast. There is a need for a wider dissemination of information on availability and use of these two sources of aid for the partially-sighted reader.

Because of the extreme disparities in visual capabilities and the relatively inflexible character of source materials presented by large-print or optical readers, the alternative of closed-circuit television (CCTV) systems should ultimately prove more useful. Several CCTV systems are now in existence or under development, but there is little information flow among the researchers. There is an urgent need for the formulation of standard specifications for the basic components and features (text support, camera mobility, camera size and display) for CCTV systems suitable to the reading behavior of the severely visually impaired.

Ideally, a "basic" CCTV design using commonly available equipment should be developed to maximize its flexibility. Semi-modular construction of these reading systems would make it possible to fit them clinically to the individual user, in the manner of a hearing aid, taking advantage of the flexibility inherent in electronic circuitry to adjust such parameters as contrast and reversal to white on black background. It is also possible to add color information, to vary illumination over the presented field, and to stabilize the retinal image of the text by introducing image motion on the picture tube that is synchronized with eyeball movements. All need to be evaluated for their potential usefulness.

A basic design should maximize the usefulness of the device as a teaching aid for children, permit speedy clinical fitting and simplify the updating of the instrument with new technical innovations as they appear.

Long Term

1. Demographic Surveys of Vocational Opportunities

It has been found that normal vision is not essential for satisfactory performance in all jobs and that the totally blind and those with severe visual impairment have performed excellently in such diverse occupations as telephone operators, X-ray film developers, computer programmers, electronics assembly-line workers, machine shop operators, etc. The blind are able to add to their skills where necessary and have exhibited considerable flexibility in adapting to the requirements of their positions. In punctuality and safety records on the job, they have no peers. Efforts must be made to determine more widely those areas of work in which normal vision is not essential and in which the blind and partially sighted may make valuable contributions.

In order to determine the capabilities of the blind and the severely visually impaired and to identify the vocational opportunities open to persons with these impairments and specific capabilities, a series of demographic vocational surveys must be undertaken. For major occupational categories, these surveys would determine the demographic (age, sex, education) characteristics suitable for entry into such occupations. In addition, for the partially sighted, data on minimum abilities needed for successful performance on the job using various visual measures (depth perception, color vision, stereoscopic vision, etc.), should be collected.

2. Public Information Programs

As a consequence of their disability, the handicapped suffer economically. For the blind, the total annual income lost has been estimated to be in the region of $0.6 to

$0.8 billion and possibly as much as $1 billion. Yet because the blind population does not constitute a market in the commercial sense, there is little incentive for the development of new technologies or even for application of existing capabilities. About $0.2 billion is currently being spent annually on income maintenance for the blind. The public should be made aware that the adequate support of research could lead to a more active participation by the blind community in our society and to a lessening of the economic burden.

3. Sensory Aids Centers

The Subcommittee's plan of action (contained in the document, "Sensory Aids for the Handicapped") points to the difficulty of the problems posed by sensory aid design and to the poorly coordinated research which is now being carried out. To meet the needs of the blind, the Subcommittee believes that a coordinated, well-funded, and well-directed national program is essential. This program must cover a full range of activities, from basic research on human information processing through device design, development, evaluation, and production. The Subcommittee believes that this work could be centered in institutions organized in the form of national centers, national laboratories, or national foundations. A major objective would be to provide first-class facilities capable of attracting the country's top talent.

If sensory aids are to be adequately deployed, however, the duties of the centers must extend beyond the development and evaluation stage. During the past twenty years of experimentation, design and laboratory evaluation of biomedical engineering products, it has become apparent that several devices could have potential benefit to certain segments of the population. They nevertheless are unavailable to compete in the commercial market due to low projected returns on investment. Having little commercial attraction, they fail to achieve manufacture and deployment. The field of sensory aids, too, contains examples of this inability to bridge the gap between research and deployment. The central problem is lack of venture capital. A possible resolution of the main difficulties may lie in the formation of a private-public

corporation charged with the development and market introduction of really promising products or in assigning the task to a National Center for Sensory Aids Development. A combination of government funding and financial participation by both industry and organizations concerned with health and physical impairment could provide adequate resources to start the process of sensory aid production with the most promising candidates. Of course, the choice of particular products would be a difficult one (as it always is in a free-enterprise economy where profit and capital gains are the lure), but a separate corporation with its own organization, free of direct influence from the network of federal and private agencies that support and perform research, would insure a new unencumbered stance in deciding which particular ventures merit support.

The management resources of such a corporation should include access to experts who are knowledgeable about the relevant medical and/or rehabilitation fields, market analysis and estimation, production procedures and costs, distribution, sales, etc. The actual make-up of the corporation might range from a small but thoroughly competent managerial team that would subcontract tasks, to the other extreme of complete in-house competence. However, such an organization, whatever its scope, must not subsume a role in the routine manufacture and sale of successful products (where success implies market acceptance and realized or potential profit). Its central preoccupation must be with the transition from research through the initiation of commercial production and deployment, after which it must divorce itself from success in order to commit its resources to new opportunities. The manufacture, distribution, and sale of successful systems must be assumed by private enterprise, for which exclusive licensing arrangements could prove an inducement. Pay-back royalties or provisions from sales could permit reinstatement of the capital resources of the proposed development corporation.

4. Computer-Aided Studies of Mobility

The design of a mobility aid for use by a blind man requires a detailed knowledge of his needs and perceptual

motor capabilities, and a thorough understanding of the interaction of the user and the machine. In the absence of any theoretical framework for studies of human mobility, progress appears possible only through a process of empirical experimentation. The problem of mobility has many dimensions and must be approached with an experimental design that is both flexible and open to a systematic exploration of a large field of alternatives. A real-time mobility simulator appears to meet these requirements. Such a system should employ a large area in which various types of terrain can be constructed. Surveillance equipment would track the position of the subject and the position and orientation of a simulated mobility aid transducer and transmit this information to a computer. The computer would be programmed to use this information to compute and feed back to the subject a signal appropriate to any one of a wide range of alternative information-processing algorithms and transducers. Observation and measurement of the subject's performance using various mobility aid systems would lead to an optimization of the device/man interface and the eventual production of more effective mobility aids.

5. Research on Pattern Processing

It has recently been demonstrated in practical situations that an array of tactile stimulators provides an effective method for presenting images (e.g., alphanumeric) consisting of a few hundred points. Techniques for manufacture of small, portable arrays of several hundred tactile stimulators are at hand. Unprocessed images consisting of less than 10,000 points, however, are insufficient for mobility and for unambiguous environmental sensing in real-life situations, yet there is some doubt that a display size of more than 1,000 stimulators can be comprehended tactually. Estimates of the effect on mobility of the resolution and field of view implied by a 1,000-point optical-to-tactile image converter indicate that the direct approach of a one-to-one mapping between photosensors and tactile stimulators is not practical.

The approach of processing the raw image data so that the important information can be displayed with fewer image points appears to be a way out of this dilemma. But while these image-processing techniques have been shown to

work in situations in which the input images are constrained in some way, such as character recognition, they are not general enough or reliable enough to work in unconstrained situations, such as those encountered in ordinary mobility.

However, a collection of image-processing transformations, with feedback control by the user so that combinations could be applied at will, may prove both useful and practical to implement. If this approach is selected, two lines of research should be pursued. First, various image transformations should be investigated to determine the number of useful image-processing techniques and the situations in which they are most useful. Second, ways of controlling this processing need study, including both what functions should be controlled and how the control signals can be extracted from the operator. The end result would be an optical input device that could display the raw image data (with a variable magnification) on a tactile display or one that could process the image according to a variety of processing algorithms and display the result. These options should be under rapid and continuous control of the blind person, perhaps by a small, portable, keyboard-like device.

6. Research on Sighted Reading

Central to efforts toward the design of reading machines is an understanding of the process involved in reading. This knowledge must be brought to bear on the problem in such a way as to optimize the blind man's access to printed matter. Evidence from modern studies of reading indicates that the information in a printed sequence is acquired at many different levels. The fact that visual letter-by-letter reading is limited to a rate of about 40 words per minute indicates that in normal reading (which can take place at speeds up to 500 wpm or more) not every letter is seen. A similar finding is indicated at the word level where linguistic factors influence recognition speed and accuracy. Thus the sequence of words and the semantic and syntactic context of the word is important in determining the readiness with which any particular word is identified. Comprehension depends on identifying the correct manner. Furthermore, the pattern of scanning eye movements

is closely bound to both of these processes. These factors all are of more than superficial importance and require close study because in reading by ear or by touch they indicate the need for various degrees of control over the rate and span of information available at any given time. Experimental data appear to suggest that this kind of control would enhance the reader's overall speed and efficiency of comprehension.

7. Automated Reading Services via Telephone

Recent studies indicate that it is now technologically possible to link blind individuals to a central, time-shared computer facility for remote reading of documents. Personally owned, relatively inexpensive scanners could accept typewritten or printed documents such as letters, bills, bank statements, newspapers, and magazines fed in by the blind user from his home or office. Electrically encoded representation, line-by-line, could be transmitted directly via telephone lines to the central facility. A conventional high-speed and time-shared digital computer at the central facility could be programmed to recognize multi-font type. The printed material thus "read" would then be automatically translated into spoken output (synthesized speech), braille, or tactile-transducer signals and relayed via the same telephone lines back to the blind user. If the facility were located within reach of a library, talking book and braille production could be undertaken during off-peak hours and delivered to clients by mail in the normal manner. To overcome the problems created by poor-quality print, the reading facility could be designed to display unusual or computer-unreadable type so that personnel at the Center could intercept it and read it directly.

Before such a system can be designed, however, pilot studies are required to examine such factors as the potential market demand, clients' desires and needs, the number of subscribers required for efficient use of the facility, time-sharing loads and schedules, tradeoffs on remote vs. central equipment complexity, probable costs and possible levels of subsidy. These studies might be used to encourage development of the system.

EPILOGUE

To those currently involved in the field of sensory aids research and development, the Subcommittee's assessment of urgent needs presented above can serve as a checklist against which other views and proposals can be weighed. For those searching for new opportunities, it is hoped that the brief discussion has provided the first step in the process of identifying challenges and developing innovative approaches to meet them.

Except for an occasional hint of potentially fruitful avenues which merit consideration, the creation of definitive projects in any of the listed proposals is left to those who will carry them out. To aid in this endeavor, the following pages list basic source documents that define more completely the problems extant in this field, describe the current state-of-the-art, and indicate places and people currently active in the field. These source documents abound in reference citations that cover the relevant literature.

Lastly, the reader is reminded of the desire of the Subcommittee to communicate with those having mutual interests. The address to be used for this purpose is found on page two.

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